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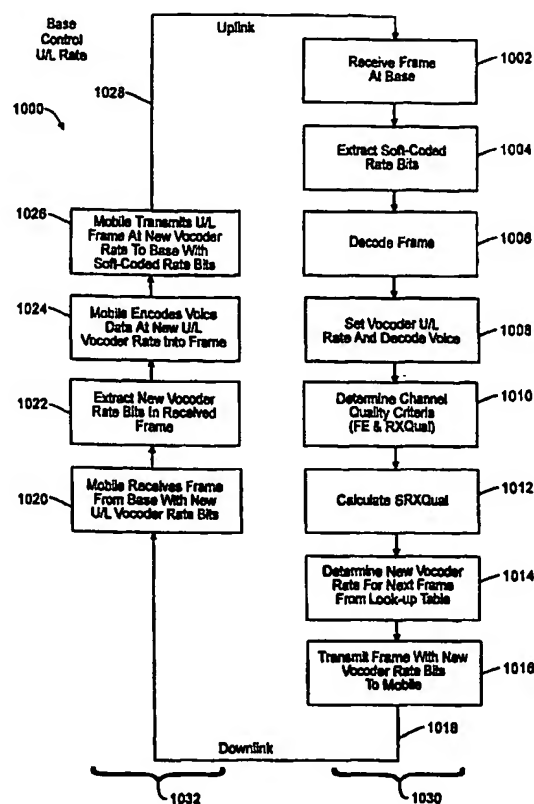
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(54) Title: SYSTEM AND METHOD FOR RATE ADAPTATION OF A MULTIRATE VOCODER

(57) Abstract

The present invention includes a time-division-multiple-access (TDMA) communication system having a base station and at least one mobile station, each transmitting and receiving an analog radio-frequency signal carrying digital coded speech. The speech is encoded using a vocoder which samples a voice signal at variable encoding rates. During periods when the radio-frequency channel is experiencing high levels of channel interference, the encoded voice channel having a lower encoding rate is chosen. This low-rate encoded voice is combined with the high degree of channel coding necessary to ensure reliable transmission. When the radio-frequency channel is experiencing low levels of channel interference, less channel coding is necessary and the vocoder having a higher encoding rate is used. The high-rate encoded voice is combined with the lower degree of channel coding necessary to ensure reliable transmission. The appropriate levels of channel coding necessary for reliable transmission are determined by various channel metrics, such as frame erasure rate and bit error rate. The determination of the appropriate vocoder rate and level of channel coding for both the uplink and downlink may be determined centrally at the base station, with the vocoder rate and level of channel coding for the uplink being relayed to the mobile station. Alternatively, the appropriate vocoder rate and level of channel coding for the downlink may be determined by the mobile station, and the appropriate vocoder rate and level of channel coding for the uplink may be determined by the base station.



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2       SYSTEM AND METHOD FOR RATE ADAPTATION OF A MULTIRATE VOCODER

3                               **BACKGROUND OF THE INVENTION**4       Field of the Invention

5           The present invention relates generally to wireless communication  
6 systems. More particularly, the present invention relates to a wireless  
7 communication system having an adaptive multi-rate (AMR) vocoder to  
8 maximize the voice quality while minimizing the level of channel coding.

9       Description of the Related Art

10          As the use of wireless communication systems become increasingly  
11 popular, a variety of methods are being developed to increase the number of  
12 mobile communication devices a system can simultaneously service. The  
13 Global System for Mobile Communications (GSM), also referred to as the  
14 Group Speciale Mobile, is one example of a wireless communication system  
15 which is constantly being adapted to increase the number of simultaneous  
16 users.

17          The GSM system is modeled after standards created by the European  
18 Telecommunications Standards Institute (ETSI) and operates between a  
19 telecommunication base station (BS) and a mobile station (MS) using a pair  
20 of frequency bands in a frequency division duplex (FDD) configuration. The  
21 first frequency band occupies the frequency spectrum between 890 to 915  
22 Megahertz (MHZ), and the second frequency band occupies the frequency

1 spectrum between 935 to 960 MHz. Typically, the first frequency range is  
2 used for the lower power transmissions from the MS to the BS, and the  
3 second frequency range is used for the higher power transmission from the  
4 BS to the MS. Each frequency range is divided into 125 channels with 200  
5 KiloHertz (kHz) spaced carrier frequencies.

6 The GSM communication system is a time-division-multiple-access  
7 (TDMA) system. In the GSM TDMA system, each carrier frequency is divided  
8 into eight (8) time slots. Because each MS is assigned a single time slot on  
9 one channel in both the first frequency range and the second frequency  
10 range, a total of 992 MS may use the BS at the same time.

11 A typical speech channel for GSM communication is sampled at 8 KHz  
12 and quantized to a resolution of 13 bits, providing for the digitization of  
13 speech ranging from 0 - 4 KHz by a voice encoder, also referred to as a  
14 vocoder. The 13 bits are then compressed by a factor of eight (8) in a full-  
15 rate vocoder to a voice data digital bit stream of 13 kilobits per second  
16 (Kbit/s). Because GSM uses a complex encryption technique with  
17 interleaving and convolution coding, a high degree of system integrity and bit  
18 error control are achieved. In fact, despite multi-path and co-channel  
19 interference, the GSM system may continue to operate despite a carrier-to-  
20 interference ratio (C/I) as low as 9 dB, in comparison to a typical advanced  
21 mobile phone service (AMPS) analog system requiring a maximum C/I of 17  
22 dB.

1            Depending upon the topography of an area, a typical BS may provide  
2        communication services to any number of MSs within a radius up to 35  
3        Kilometers. Consequently, with the rising popularity of mobile communication  
4        devices, it is often the case that during peak periods of use, such as rush-  
5        hour traffic, all channels are fully occupied and the BS is not able to provide  
6        communication services all of the MS in its region.

7            In order to avoid the inability to service all MS within a region, the ETSI  
8        has contemplated a modification of the GSM standard to increase the density  
9        of the communication channels. However, because the allocated frequency  
10       spectrum of 25 MHz with 125 separate 200 KHz carrier channels is fixed, a  
11       current approach to increasing the density of the communication system is to  
12       increase the number of users per channel. In general, this density increase is  
13       achieved by decreasing the amount of digital information which is sent to and  
14       from each BS, thereby allowing each BS to support more users in a 200 kHz  
15       frequency band.

16           One approach to decreasing the amount of digital information passing  
17        between a BS and a MS is to decrease the vocoder rate of the digital voice  
18        data from a full-rate vocoder rate of 13 kilobits per second (Kbits/s) to a half-  
19        rate vocoder rate of 5.6 Kbits/s. Although the ability currently exists to  
20        effectively double the number of users on any one communication channel  
21        from eight (8) to sixteen (16) by using the half-rate vocoder, it has been found  
22        that the 5.6 Kbits/s vocoder rate is barely acceptable as the speech quality is  
23        significantly decreased.

1           In light of the above, it would be advantageous to provide a  
2   communication system that provides for the user density of a half-rate  
3   vocoder system, while providing the voice quality approaching or exceeding  
4   that of a full-rate vocoder system. It would also be advantageous to provide  
5   a communication system that provides for the modification of the  
6   communication channel to incorporate only the amount of channel coding  
7   necessary to achieve a reliable communication link between the MS and the  
8   BS.

1                                    **SUMMARY OF THE INVENTION**

2            Broadly, the present invention provides for a wireless communication  
3    system having the ability to increase or decrease the vocoder rate and  
4    channel coding in response to the level of interference present on the  
5    wireless communication channel, resulting in a communication channel  
6    having the best possible speech quality. This may be accomplished in either  
7    a full-rate or half-rate GSM communication system by decreasing the amount  
8    of channel coding during periods of low channel interference to allow  
9    transmission of more speech information, representing a higher vocoder rate  
10   and resulting in a higher speech quality. During periods of higher channel  
11   interference, the amount of channel coding may be increased to the  
12   maximum channel coding allowed in a GSM communication network. This  
13   increased channel coding provides for consistent and reliable call handling,  
14   and results in a lower vocoder rate having a lower speech quality.

15           In an embodiment of the present invention, a time-division-multiple-  
16   access (TDMA) communication system includes a base station (BS) and at  
17   least one mobile station (MS), each transmitting and receiving an analog  
18   radio-frequency signal carrying digitally coded speech. The speech is  
19   digitally encoded using a vocoder which samples a voice signal at different  
20   encoding rates. Alternatively, the speech may be encoded using a number of  
21   different vocoders simultaneously, with each vocoder having a different  
22   encoding rate. During periods when the radio-frequency channel is  
23   experiencing high levels of channel noise or interference, the encoded voice

1 channel having a lower encoding rate is chosen. This lower-rate encoded  
2 voice is combined with the high degree of channel coding necessary to  
3 ensure reliable transmission. When the radio-frequency channel is  
4 experiencing low levels of channel interference, less channel coding is  
5 necessary and the vocoder having a higher encoding rate is used. The high-  
6 rate encoded voice is combined with the lower degree of channel coding  
7 necessary to ensure reliable transmission. The appropriate level of channel  
8 coding necessary for reliable transmission is determined by various channel  
9 metrics, such as frame erase rate and bit error rate.

10 The determination of the appropriate vocoder rate and level of channel  
11 coding for both the uplink and downlink may be determined centrally at the  
12 base station, with the vocoder rate and level of channel coding for the uplink  
13 being relayed to the mobile station. Alternatively, the appropriate vocoder  
14 rate and level of channel coding for the downlink may be determined by the  
15 mobile station, and the appropriate vocoder rate and level of channel coding  
16 for the uplink may be determined by the base station.

#### 17 **BRIEF DESCRIPTION OF THE DRAWINGS**

18 The nature, objects, and advantages of the invention will become more  
19 apparent to those skilled in the art after considering the following detailed  
20 description in connection with the accompanying drawings, in which like  
21 reference numerals designate like parts throughout, wherein:



1           Figure 1 is a diagram of a typical wireless telecommunication system,  
2   including a base station and a number of mobile stations;

3           Figure 2 is a schematic diagram of the hardware of a typical wireless  
4   transceiver of the present invention and includes three separate vocoders,  
5   each having a different vocoder rate;

6           Figure 3 is a graph of the relative performance characteristics of a  
7   wireless communication system implementing a variable vocoder rate;

8           Figure 4 illustrates the coding, combination and interleaving of speech  
9   blocks into a frame, and the variation of the ratio of channel coding to speech  
10   coding for various levels of radio-frequency channel noise and interference;

11          Figure 5 is a state diagram illustrating the change of vocoder rate  
12   based upon the current status of the communication system, including the FE  
13   and BER metrics;

14          Figure 6 depicts a sequence of steps which are performed in the  
15   communication system wherein the mobile station calculates the downlink  
16   vocoder rate based on its calculations of a number of channel quality metrics;

17          Figure 7 depicts a sequence of steps which are performed in the  
18   communication system wherein the mobile station forwards its channel  
19   quality metrics to the base station where the vocoder rate for the downlink is  
20   determined and communicated to the mobile station;

21          Figure 8 is a quantization table identifying the bits transmitted from the  
22   mobile station to the base station in order to provide the base station with the

- 1    necessary channel metric information to determine the mobile stations
- 2    vocoder rate;
- 3        Figure 9 is a quantization table identifying the received bits which
- 4    correspond to the channel quality metrics made by the mobile station; and
- 5        Figure 10 depicts a sequence of steps which are performed in the
- 6    communication system wherein the base station calculates the uplink
- 7    vocoder rate based on its calculations of a number of channel quality metrics.

1                                    **DETAILED DESCRIPTION**

2    **System Architecture of a Preferred Embodiment**

3            Referring first to Figure 1, an exemplary communication system of the  
4    present invention is shown and generally designated 100. Communication  
5    system 100 operates in compliance with the GSM communication standard  
6    which includes a time-division-multiple-access (TDMA) communication  
7    scheme. In general, a TDMA communication system provides for the  
8    transmission of two or more data channels over the same radio-frequency  
9    channel by allocating separate time intervals for the transmission of each  
10   data channel. In a GSM system, each 200 kilohertz (kHz) radio-frequency  
11   channel is divided into repeating time frames, each frame having a duration  
12   of 4.615 milliseconds. Each frame contains eight (8) time intervals (also  
13   called "slots") each having a duration of 577 microseconds ( $4,615/8$ ) and  
14   assigned to a different user.

15           Communication system 100 includes a base station (BS) 102 which  
16   receives signals from a mobile switching center (MSC) 106 via  
17   communication channel 108. This communication channel includes  
18   telephone and/or digital information which may typically originate from land-  
19   based telephone systems. Base station 102 transmits information to, and  
20   receives information from, mobile stations (MS) 110, 112, and 114 which are  
21   within cell 120. Cell 120 is a geographical region within which all mobile  
22   stations communicate with the base station 102. Typically, these cells range

1 may have radii ranging from twenty-five (25) to thirty-five (35) kilometers, and  
2 may include such geographical disturbances such as buildings 130 or  
3 mountains 132. As used herein, the term "information" shall be defined to  
4 include digital data, encrypted digital data, convolutionally coded, soft-coded,  
5 and/or hard-coded data, digital bits or a bit stream, or any other data type  
6 known in the art.

7       Because a GSM-based communication system operates with paired  
8 frequency bands in a frequency-division-duplex (FDD) mode, base station  
9 (BS) 102 sends information to the mobile station (MS) 110 over a first radio-  
10 frequency channel 116, typically in the 890 to 915 MHz range and referred to  
11 as the "downlink," and mobile station 110 sends information to the base  
12 station 102 over a second radio-frequency channel 118, typically in the 935 to  
13 960 MHz range and referred to as the "uplink." Although a GSM-based  
14 communication system operates using two frequency bands, it is nonetheless  
15 possible to implement the present invention in a system where both the BS  
16 and MS transmit and receive over the same radio-frequency channel.

17       Communication system 100 may support a number of mobile stations  
18 (MSs) 110, 112, and 114. In fact, under the GSM standard, each 25 MHz  
19 frequency band is divided into 125 channels with 200 Kiloherztz (KHz) spaced  
20 carrier frequencies. With each carrier frequency supporting eight (8)  
21 separate users, a single GSM communication system may support nearly one  
22 thousand (1,000) simultaneous users.

1           Given the high possible number of simultaneous users contributing to  
2 co-channel interference, and the presence of atmospheric and geographical  
3 sources of interference, there are periods of time during which a considerable  
4 amount of channel noise and interference is present on the communication  
5 system 100. Moreover, the presence of buildings 130 and mountains 132  
6 result in multi-path distortion which further degrade the reliability of  
7 transmissions through the communication system 100. Additionally, because  
8 each MS may be moving in a different direction with respect to the BS, either  
9 towards or away from the BS at speeds up to 250 kilometers-per-hour (156  
10 miles-per-hour), the possibility that a communication link will be temporarily or  
11 permanently disrupted is even higher.

12           In an attempt to minimize the deleterious effects of channel noise and  
13 interference on both the uplink and downlink communication channels, a  
14 significant amount of channel coding is added to the digital voice data.  
15 Channel coding is generally defined to include the process of combining the  
16 encoded digital voice data from the vocoder, with any redundant data, parity  
17 data, cyclic-redundant-checking (CRC) or other check data necessary to  
18 ensure the reliable transmission of the voice data. The code rate is the ratio  
19 of data bits to total bits ( $k/n$ ), and is typically just over one-half ( $1/2$ ) in an  
20 ordinary GSM-based system with full-rate vocoders, and just below one-half  
21 ( $1/2$ ) in a system with half-rate vocoders.

22           During the channel coding process, the introduction of the necessary  
23 error correction, redundant data, parity data, CRC or check data is

1 accomplished by convolutionally coding the digital voice data from the  
2 vocoder, with the necessary channel coding data. This results in a  
3 convolutionally encoded digital data stream which includes a mixture of voice  
4 data and channel coding. As will be more thoroughly discussed in  
5 conjunction with Figure 2, this digital data stream is modulated and amplified  
6 for transmission over a radio-frequency channel. Upon reception of the  
7 modulated digital data stream, the data stream is channel de-modulated and  
8 the voice data and channel coding is convolutionally decoded and separated.

9       During periods with high levels of channel noise, the introduction of  
10 significant channel coding provides for an increased reliability of the  
11 communication channel. On the other hand, a data stream containing a  
12 significant amount of channel coding information limits the amount of voice  
13 data which can be transmitted, and during periods of low channel noise,  
14 results in an inefficient use of the communication channel. Consequently, the  
15 present invention monitors the current level of channel noise, and either  
16 increases the amount of channel coding to improve channel reliability, or  
17 decreases the amount of channel coding to provide for the transmission of  
18 more voice data.

19       Although the current GSM-based communication systems dictate a  
20 maximum vocoder rate of 13 Kbits/s for a full-rate vocoder system, the  
21 present invention contemplates a much higher maximum vocoder rate up to  
22 the bandwidth limitation of the wireless communication channel itself. For  
23 instance, if the current level of channel noise or interference is minimal, it is

1 possible to provide a communication link having virtually no channel coding  
2 and thus providing for a voice data rate of 22 Kbits/s. This would correspond  
3 to a voice bandwidth over 4 kHz, resulting in a voice channel having a  
4 frequency range and corresponding voice quality well beyond that of a  
5 traditional 4 kHz voice bandwidth.

#### 6 Transceiver Architecture

7 Referring now to Figure 2, a circuit diagram of a transceiver of one  
8 embodiment of the present invention is shown and generally designated 200.  
9 The transmitter portion of circuit 200 includes a microphone element 202,  
10 such as an electret-type microphone, that receives an acoustic signal, such  
11 as a user's voice, and converts the acoustic voice signal to an analog  
12 electrical signal. This analog electrical signal passes through amplifier 204  
13 for amplification and filtering, and is supplied to the inputs of three (3)  
14 separate voice encoders, or vocoders 206, 208, and 210.

15 A vocoder is an analog-to-digital converter (ADC) which is created  
16 especially for the digital encoding and compression of analog voice data.  
17 Vocoders are designed around high speed digital signal processors (DSPs)  
18 and use a form of linear predictive coding which is intended to model the  
19 human vocal chords in order to produce realistic synthetic speech with the  
20 minimum of memory. In a GSM communication system with full-rate  
21 vocoders, voice data is sampled at the rate of 8 kHz and quantized to a  
22 resolution of thirteen (13) bits and compressed to a bit rate of 13 Kbits/s. In a

1 GSM communication system with half-rate vocoders. voice data is sampled at  
2 the rate of 8 kHz and quantized to a resolution of thirteen (13) bits and  
3 compressed to give a bit rate of 5.6 Kbits/s.

4 In the present invention, vocoders 206, 208, and 210 each receives  
5 the amplified voice signal from amplifier 204 and each vocoder is  
6 continuously encoding the acoustic voice signals at different rates. For  
7 example, vocoder 206 may encode the voice signal at a vocoder rate of 8  
8 Kbits/s, vocoder 208 may encode the voice signal at a lower vocoder rate of 6  
9 Kbits/s, and vocoder 210 may encode the voice signal at an even lower  
10 vocoder rate of 4 Kbits/s. The particular vocoder rates discussed herein are  
11 merely exemplary, and it is to be appreciated that a vocoder of virtually any  
12 rate may be used, so long as the representative digital data rate is capable of  
13 being transmitted over the radio-frequency communication channel.

14 The outputs from vocoders 206, 208 and 210 are fed into switch 212  
15 which is controlled by processor 214 having a memory storage 215.  
16 Processor 214 in the present embodiment is a microprocessor. However,  
17 processor 214 may instead be any conventional single or multi-chipped  
18 microprocessor, digital signal processor, microcontroller, or any other suitable  
19 digital processing apparatus known in the art. Memory storage 215 in the  
20 present embodiment may include an electrically erasable programmable  
21 read-only-memory (EEPROM), read-only-memory (ROM), random-access-  
22 memory (RAM), diskettes or other magnetic recording media, optical storage  
23 media, or any combination thereof. Electronic instructions for controlling the



1 operation of processor 214, in the form of program code, may be stored in  
2 memory storage 215.

3 Based upon a predefined selection process, described in greater detail  
4 below, processor 214 determines the proper vocoder rate and selects the  
5 output of the appropriate vocoder 206, 208 or 210 for passage through switch  
6 212 to encoder 216. For example, if the voice signal is to be encoded at a  
7 full-rate of 8 Kbits/s, then the output of vocoder 206 would be selected by  
8 processor 214 and passed through switch 212. Alternatively, if the voice is to  
9 be encoded at the rate of 6 Kbits/s, the output of vocoder 208 would be  
10 selected. Encoder 216 receives the digital voice data from the vocoder and  
11 adds the level of channel coding corresponding to the vocoder rate selected.

12 Once passed through encoder 216, the now-encoded digital voice  
13 data is mixed with the analog output of voltage-controlled-oscillator (VCO)  
14 218 to modulate the digital voice data onto a carrier frequency in modulator  
15 220. Modulator 220 modulates a gaussian-minimum-shift-key (GMSK) signal  
16 on a radio-frequency carrier which is then passed through variable power  
17 amplifier 222 and through transmit/receive switch 224 to antenna 226 for  
18 transmission. A GMSK signal incorporates gaussian-shaped pulses and is  
19 intended improve the resilience of the communication channel to co-channel  
20 interference. As an alternative to GMSK, other modulation methods known in  
21 the art may be used, such as BPSK, QPSK, or FSK.

1           Control of transmit/receive switch 224 is accomplished by processor  
2   214 in a method well known in the art. In single antenna transceivers, it is  
3   often necessary to switch the antenna between the transmitting and receiving  
4   portions of the circuitry in order to isolate the sensitive receiver electronics  
5   from the higher power signal generated by the transmitter.

6           The receiver portion of circuit 200 begins with antenna 226 which  
7   receives an analog radio-frequency signal that is passed through  
8   transmit/receive switch 224 to intermediate-frequency (IF) amplifier and mixer  
9   240. Mixer 240 removes the carrier frequency from the radio-frequency  
10   signal and passes the remaining analog signal to an analog-to-digital  
11   converter (ADC) 242. ADC 242 converts the received analog signal to a  
12   digital signal which is then passed through equalization block 244 where the  
13   digital signal may be filtered and the digital bit stream recovered, and to  
14   channel decoder 246.

15          As will be discussed in more detail below, processor 214 receives a  
16   signal, in the form of rate bits, from channel decoder 246. These rate bits  
17   identify the appropriate vocoder rate needed to decode the current voice data  
18   encoded in the received signal. Based upon the rate bits, processor 214  
19   selects vocoder 250, 252, or 254 using switch 248, and the digital voice data  
20   from the decoded radio-frequency channel is passed from channel decoder  
21   246, through switch 248, and to the appropriate vocoder 250, 252, or 254.  
22   For example, if the digital voice data was encoded at a full-rate of 8 Kbits/s,  
23   then processor 214 would operate switch 248 to send the digital voice data to

1   vocoder 250 which, in the present embodiment, decodes at the full-rate of 8  
2   Kbits/s. Vocoder 250 decodes the digital information received from channel  
3   decoder 246, and re-creates the original analog voice signal which is then  
4   passed through amplifier 256 and out speaker 258 to be heard by the user.

5           In an alternative embodiment, vocoders 206, 208 and 210 of circuit  
6   200 may be replaced by a single vocoder (shown by dashed lines 270)  
7   having multiple encoding rates, or a variable encoding rate. For instance, the  
8   single variable-rate vocoder 270 may be capable of encoding acoustic signals  
9   from amplifier 204 at rates between 4 Kbits/s, and 8 Kbits/s as determined by  
10   processor 214. Similarly, vocoders 250, 252, and 254 may be replaced by a  
11   single variable vocoder 272.

12           Although the present invention is discussed in conjunction with a  
13   TDMA communication system, it is to be appreciated that the use of a TDMA  
14   communication scheme is merely exemplary, and the present invention may  
15   be practiced on any number of alternative communications systems, such as  
16   code-division-multiple-access (CDMA) and frequency-division-multiple-  
17   access (FDMA), for example.

18           Referring now to Figure 3, a graphical representation of system  
19   performance is shown and generally designated 300. Graph 300 includes a  
20   vertical axis 302 labeled "Voice Quality" and a horizontal axis 304 labeled  
21   "Carrier-to-Noise Ratio (C/N)." As discussed herein, the term C/N is  
22   considered to include a carrier-to-interference (C/I) portion. In summary,

1 graph 300 represents the performance of communication systems based on  
2 the level of channel coding and corresponding vocoder rates. More  
3 specifically, three separate curves are shown and each represents the  
4 performance of a particular system configuration. For example, graph 306  
5 represents the performance of a communication system using a full-rate  
6 vocoder, with a minimum level of channel coding. As can be seen, curve  
7 306 begins at a higher initial voice quality, but as the C/N decreases, the level  
8 of interference due to the lower level of channel coding eventually causes a  
9 marked decrease in the voice quality.

10 Similarly, curve 312 represents the performance of a communication  
11 system using a mid-rate vocoder with a corresponding mid-level of channel  
12 coding. Such a mid-rate vocoder rate could be 6 Kbits/s. Although the initial  
13 voice quality shown by curve 312 is maintained for a longer period, it too  
14 suffers from the interference caused by the lower level of channel coding.

15 Finally, curve 318 represents the system performance of a  
16 communication system using a low-rate vocoder with a corresponding higher  
17 level of channel coding. In this case, the high level of channel coding  
18 provides for a continuous communication link despite a significant decrease  
19 in the C/N, however, the voice quality is lower than either the system shown  
20 by curve 306 or 312.

21 In order to maintain the highest level of voice quality possible, despite  
22 the decreasing C/N, the present invention changes the voice encoding rate

1 and corresponding level of channel coding in order to maximize the voice  
2 quality. For example, in environments where the C/N ratio is high, the system  
3 uses the highest possible vocoder rate and lowest possible amount of  
4 channel coding. In this situation, because of the low levels of noise and  
5 interference on the communication channel, there is little need for heavy  
6 channel coding to ensure the communication channel is sustained. However,  
7 as the C/N ratio begins to decrease, at the precise instant when curve 306  
8 crosses curve 312, shown as intersection 310, the communication system of  
9 the present invention changes the vocoder rate and corresponding channel  
10 coding to the rate associated with curve 312. In this manner, the highest  
11 possible level of voice quality is maintained, even though there is a higher  
12 level of channel coding present.

13 Similarly, as the voice quality of the system represented by curve 312  
14 drops to the level of the system represented by curve 318, shown at  
15 intersection 316, the communication system of the present invention again  
16 changes the vocoder rate and corresponding channel coding to the rate  
17 associated with curve 318. In this manner, the voice quality for the  
18 communication channel is always maximized.

19 In the event the channel noise and interference exceeds the maximum  
20 allowable level and results in the voice quality being sufficiently poor so as to  
21 pass below the threshold 324, shown at intersection 322, the communication  
22 channel is terminated. This terminated communication channel is perceived  
23 by the user as a "dropped call." Once terminated, system 100 must be re-

1 initialized and a communication channel must be re-established between the  
2 BS 102 and the MS 110.

3 Graph 300 has been divided into three (3) regions 308, 314, and 320,  
4 representing the maximized voice quality. A communication channel using  
5 the present invention will operate within each of these regions as needed to  
6 maximize the voice quality. For example, for a communication channel which  
7 is initiated at a vocoder and channel coding rate in region 314 corresponding  
8 to curve 312, a momentary decrease in the C/N may cause the system to  
9 switch to a vocoder and channel coding rate in region 320 corresponding to  
10 curve 318. However, once the C/N returns to its original value, the system  
11 will shift back to the vocoder and channel coding rate of region 314  
12 corresponding to curve 312. In this manner, system 100 may constantly  
13 move between regions 308, 314 and 320 to maximize the voice quality of the  
14 communication channel.

15 Graph 300 has been shown to include three (3) separate curves  
16 representing three (3) different vocoder rates and corresponding levels of  
17 channel coding. However, it should be appreciated that the selection of three  
18 (3) vocoder rates is merely exemplary, and virtually any number of vocoder  
19 rates may be used in the present invention. Moreover, in a system of the  
20 present invention incorporating a vocoder having a variable vocoder rate,  
21 virtually any combination of vocoder rate and channel coding may be  
22 accomplished within the system limits, ranging from a maximum vocoder rate

1 with no channel coding, to minimum vocoder rate with maximum channel  
2 coding.

3 Referring now to Figure 4, a diagrammatic representation of the  
4 construction of a GSM communication channel is shown and generally  
5 designated 400. Representation 400 includes a series of three (3) speech  
6 blocks 402, 404, and 406. Speech block 402 includes a channel coding  
7 portion 408 and a voice data portion 410. A speech block represents the  
8 digital information which has been generated by the vocoder 206, 208 or 210  
9 and channel coder 216 of circuit 200. Accordingly, the digital information  
10 within a speech block includes both the voice data and channel coding which  
11 has been determined necessary for the reliable transmission of the  
12 information. While Figure 4 identifies a channel coding portion 408 and a  
13 voice data portion 410 as separate portions of speech block 402, it is to be  
14 appreciated that such identification is merely for discussion purposes, and the  
15 voice data is actually interleaved with the channel coding to create a data  
16 stream having 228 bits.

17 Speech blocks 402, 404 and 406 are each shown having different  
18 ratios of channel coding portions and voice data portions. More specifically,  
19 speech block 402 is shown having a larger proportion of channel coding 408  
20 to a smaller proportion 412 of voice coding 410. Speech block 404, on the  
21 other hand, has approximately an even proportion 418 of channel coding 414  
22 to voice coding 416. Speech block 406 has a larger proportion 424 of  
23 channel coding 420 to voice coding 422. In any case, from comparing

1 speech blocks 402, 404, and 406, it can be seen that the ratios of channel  
2 coding to voice coding may change, and even though three separate ratios  
3 have been shown in Figure 4, virtually any proportion 412, 418, and 424 may  
4 be implement with the present invention.

5 In addition to having a variable quantity of voice data and channel  
6 coding, a speech block may also be encoded with a number of rate bits 413.  
7 These rate bits 413 represent the particular vocoder rate with which the voice  
8 data is encoded. For example, in a communication system where vocoder  
9 rates may be varied, rate bits 413 provide the necessary vocoder rate  
10 information to successfully decode the voice data. In a preferred  
11 embodiment, the rate bits are positioned within the speech block 402, but are  
12 not convolutionally encoded with the voice data and channel coding. Rather,  
13 the rate bits 413 are "soft-coded" into the speech block 402 such that they  
14 can be extracted without the need for convolutionally decoding the speech  
15 block. The term "extract" in the present context may include convolutionally  
16 decoding, soft-decoding, hard-decoding, or any other manner of retrieving the  
17 digital information from the data stream known in the art.

18 The "soft-coding" of the rate bits may be accomplished by placing a  
19 series of bits within a particular location of the speech block. For example,  
20 rate bits 413 may be placed at bit positions 70, 71, and 72 of speech blocks  
21 402, 404 and 406. By positioning the rate bits at consistent locations within  
22 each of the speech blocks, it is not necessary to decode the block to  
23 determine the value of the rate bits. Instead, the value of the bits in bit



1 positions 70, 71 and 72 could be determined simply by scanning those bits in  
 2 the serial bit stream. Additionally, it is possible to place the rate bits in more  
 3 than one location within each speech block, providing for a measure of error  
 4 correction. For example, rate bits 413 could occur in three separate locations  
 5 within speech block 402, allowing the averaging of the bits within the three  
 6 separate locations in order to provide the best approximation of the rate bits  
 7 despite any transmissions errors.

8 In a preferred embodiment, rate bits 413 may represent a three-bit  
 9 binary value corresponding to eight distinct vocoder rates. Table 1 below  
 10 identifies such a table of eight distinct vocoder rates based upon three rate  
 11 bits. As can be seen from Table 1, the rate bits 413 may be assigned any  
 12 vocoder rate within the vocoder range of the communication system.

13	<u>Rate Bits</u>	<u>Vocoder Rate (Level)</u>	<u>Vocoder Rate</u>
14	<u>(Kbits/s)</u>		
15	000	Level 1	3.0
16	Kbits/s		
17	001	Level 2	4.0
18	Kbits/s		
19	010	Level 3	5.0
20	Kbits/s		
21	011	Level 4	6.0
22	Kbits/s		

1	100	Level 5	7.0
2	Kbits/s		
3	101	Level 6	8.0
4	Kbits/s		
5	110	Level 7	9.0
6	Kbits/s		
7	111	Level 8	10.0
8	Kbits/s		

9                                      TABLE 1 - Rate Bits for Corresponding Vocoder Rates

10            There are three (3) rate bits identified in Table 1, however, the number  
 11    of rate bits may vary depending upon the total number of vocoder rates  
 12    available. For instance, if only two rates are available, a single bit would be  
 13    needed, with a bit value of "0" indicating one rate, and the bit value of "1"  
 14    indicating the other rate. Similarly, if only four rates were available, two rate  
 15    bits would be needed, with the bit values of "00" indicating a first vocoder  
 16    rate, bit values of "01" indicating a second vocoder rate, bit values of "10"  
 17    indicating a third vocoder rate, and bit values of "11" indicating a fourth  
 18    vocoder rate.

19            Although Table 1 includes a series of eight (8) vocoder rates spaced 1  
 20    Kbits/s apart, it is to be appreciated that it is not necessary for the vocoder  
 21    rates to be evenly distributed. In fact, it would be advantageous for the  
 22    communication system of the present invention to have a number of vocoder

1 rates within the operating range most frequently experienced by the system.  
2 For example, if the communication system noise and interference  
3 characteristics indicate that the vocoder rate would typically be 6 Kbits/s, then  
4 it might be advantageous to provide several vocoder rates within the 5 to 7  
5 Kbits/s region in order to maximize the voice quality. In such an environment,  
6 a series of eight (8) vocoder rates might include the following vocoder rates:  
7 4.0 Kbits/s, 5.0 Kbits/s, 5.5 Kbits/s, 6.0 Kbits/s, 6.5 Kbits/s, 7.0 Kbits/s, 8.0  
8 Kbits/s, and 9.0 Kbits/s. Using these vocoder rates would allow the  
9 communication system to adjust the vocoder rate just slightly in order to  
10 provide the finest possible voice quality during periods of slight fluctuations in  
11 the channel noise and interference levels, while retaining the ability to  
12 significantly change the vocoder rate for periods of heavy channel noise and  
13 interference.

14         Once the voice data has been encoded with the necessary channel  
15 coding, and any rate coding, to form speech blocks 402, 404, and 406, each  
16 speech block is divided into four (4) sub-blocks. For example, "A" speech  
17 block 402 is split into sub-blocks "A<sub>1</sub>" 432, "A<sub>2</sub>" 434, "A<sub>3</sub>" 436, and "A<sub>4</sub>" 438.  
18 Likewise, "B" speech block 404 is split into sub-blocks "B<sub>1</sub>" 440, "B<sub>2</sub>" 442, "B<sub>3</sub>"  
19 444, and "B<sub>4</sub>" 446, and "C" speech block 406 is split into sub-blocks "C<sub>1</sub>" 448,  
20 "C<sub>2</sub>" 450, "C<sub>3</sub>" 452, and "C<sub>4</sub>" 454. In this manner, the 228 bit data stream in  
21 the speech block is broken into four (4) sub-blocks of 57 bits each.

22         Using a combination of sub-blocks, a multi-frame 476 is constructed  
23 which includes a continual string of data frames, with each data frame having

1 eight (8) time slots 478, 480 and 482. As shown by mapping lines 462 and  
2 464 in Figure 4, frame 478 is constructed from the "A<sub>3</sub>" sub-block 436 and the  
3 "B<sub>1</sub>" sub-block 440. This combination of sub-blocks into frames 478, 480 and  
4 482 is called "frame-interleaving" and is intended to create a more robust  
5 communication channel.

6 In addition to this frame-interleaving, the even bits within frame 478  
7 are comprised of the data bits of the "B<sub>1</sub>" sub-block 440, and the odd bits  
8 within frame 478 are comprised of data bits of the "A<sub>3</sub>" sub-block 436. This  
9 even bit/odd bit combination is called "bit-interleaving" and results in the  
10 distribution of a single speech block over four contiguous frames. This  
11 distribution provides for an improved fault tolerance for the communication  
12 system, and in circumstances where the noise level and interference level are  
13 high, results in a more resilient communication channel.

14 In addition to the combination of sub-blocks 438 and 442, frame 480 is  
15 also encoded with communication system specific coding. For example,  
16 using the GSM-based communication system of Figure 1, frame 480 is  
17 encoded with three (3) leading "tail bits" 482, a first "encoded voice" bit  
18 stream 484 of fifty-seven (57) bits, a single "flag" bit 486, a twenty-eight bit  
19 "training sequence" 488, a second "flag" bit 490, a second "encoded voice" bit  
20 stream 492 of fifty-seven (57) bits, three (3) trailing "tail bits" 494, and an  
21 eight and one-quarter (8¼) bit "guard" period 496. The first and second  
22 "encoded voice" bit streams 484 and 492 represent the encoded voice which

1 was present in the "B<sub>1</sub>" sub-block 440 and the "A<sub>3</sub>" sub-block 436, which  
2 included both the voice data, channel coding, and rate bits.

3 Because Doppler shift and multi-path echoes in system 100 can affect  
4 the received signal quality, each TDMA frame must include training sequence  
5 488, also called training bits. The receiver in system 100 compares these  
6 training bits with a known training pattern, and from this deduces the transfer  
7 function of the propagation path. An adaptive filter is then created within  
8 processor 214 to perform the inverse transfer function, thus canceling any  
9 unacceptable distortion. This adaptive filtering is well known in the art, and is  
10 thus not discussed in more detail here.

11 Because of the frame-interleaving and bit-interleaving employed in this  
12 GSM-based communication system 100, it is not possible to decode the voice  
13 information without re-assembling the sub-blocks 432 - 454 from successive  
14 frames 478 - 482 in multi-frame 476. Consequently, it is necessary for the  
15 digitally encoded voice information to be temporarily stored, such as by  
16 temporarily placing the encoded voice information into storage 215 of circuit  
17 200. Once a sufficient number of frames has been stored in memory storage  
18 215, the sub-blocks are then re-assembled and the voice data is decoded  
19 from the re-constructed speech blocks, removing all channel coding, and  
20 sent through switch 248 to vocoders 250, 252, and 254.

21 A full-rate GSM-based system would assign each time slot within a  
22 frame to a different user. For example, each of the eight (8) time slots within

1 a frame would be assigned to eight (8) different users. In a half-rate GSM-  
2 based system, the frame and slot timing remains the same, but instead of a  
3 user being assigned a time slot in every frame, the user is assigned a time  
4 slot in every other frame.

5 **OPERATION**

6 **Communication Channel Metrics**

7 The operation for the present invention includes the modification of the  
8 vocoder rate and level of channel coding to provide the best possible voice  
9 quality, while ensuring a reliable communication channel. In order to  
10 determine the appropriate level of channel coding necessary to provide  
11 reliable communication, a number of channel quality metrics are considered  
12 by the present invention. Defined generally, these channel quality metrics  
13 include characteristics of the communication channel which may be  
14 measured, and by continually measuring these channel quality metrics, an  
15 accurate evaluation of the channel quality may be made.

16 One channel metric used to evaluate the quality of the communication  
17 channel is the uncoded Bit Error Rate (BER). The uncoded BER of a  
18 communication channel is defined as the ratio of the number of bits in a data  
19 stream which are improperly demodulated to the total number of bits  
20 transmitted. In general, a bit error is caused when the noise power level in a  
21 communication system becomes comparable to the energy level in each bit  
22 transmitted. Consequently, in a system with a small channel-to-noise ratio

(C/N), bit errors are more likely. Conversely, in a system with a large channel-to-noise ratio, bit errors are less likely. Thus, on a fundamental level, the rate of occurrence of bit errors, or the BER, provides an overall system quality metric.

An additional metric which may be used to evaluate the quality of a communication channel is the RX Quality (RXQ) indicator. The RXQ indicator as generally known in the industry is assigned a value by the network, indicating the quality of the received signal based upon the current BER. Table 2 below includes values for a typical network-determined BER with corresponding RXQ values. This table, however, represents an average received quality, and not an instantaneous RXQ value.

<u>RX Qual</u>	<u>Corresponding Bit Error Rate</u>	<u>Range of Actual BER</u>
(%)		
0	Below 0.2	Below 0.1
1	0.2 to 0.4	0.26 to 0.30
2	0.4 to 0.8	0.51 to 0.64
3	0.8 to 1.6	1.0 to 1.3
4	1.6 to 3.2	1.9 to 2.7
5	3.2 to 6.4	3.8 to 5.4
6	6.4 to 12.8	7.6 to 11.0
7	above 12.8	above 15

1 Table 2 - GSM Standards for RX Quality Metric

2 The GSM standards for the RXQ of Table 1 is an average value  
3 measured during a predefined period of time. However, because the present  
4 invention contemplates an immediate response to a decrease in the RXQ  
5 value, it is necessary to determine the RXQ metric on a block-by-block basis.  
6 This block-by-block calculation of RXQ', for example, would be made within  
7 the MS for the downlink, and within the BS for the uplink.

8 In the present invention, an RXQ' metric is defined and is dynamically  
9 measured by re-encoding the decoded voice data coming out of the  
10 convolutional decoder, and comparing them against the received bits. The  
11 RXQ' value represents the number of bits different between the received bits  
12 and the re-encoded bits per block. The RXQ' consequently provides a  
13 combined indication of bit error rate and receiver quality for each block.

Referring briefly to Figures 2 and 4, the determination of the RXQ' metric is accomplished by decoding the voice data from a speech block 402 within a received frame 480, and re-coding the voice data for comparison to the encoded received data. The determination of the RXQ' metric takes place within circuit 200 by receiving a transmitted frame 480 and passing the frame through transmit/receive switch 224 to intermediate frequency (IF) amplifier and mixer 240, through ADC 242 and equalizer 244, to channel decoder 246. In channel decoder 246, the frame 480 is decoded to the original speech block which is then passed to storage 215 for later use.



1 Following storage of the original speech block, all channel coding is removed  
2 to recover the original voice data which may also be stored in storage 215, or  
3 passed on through switch 248 to vocoders 250, 252 or 254 for conversion to  
4 audio.

5       Once the original voice data is recovered from channel decoder 246,  
6 the now-decoded voice data is then re-encoded through a convolutional  
7 coding process identical to that of the channel encoder 216 to exactly re-  
8 create the original coded speech block. This re-encoding may be  
9 accomplished using channel decoder 246, or the voice data may be passed  
10 through a separate channel coder 247. By comparing the original speech  
11 block stored in storage 215 with the newly re-coded speech block from  
12 channel coder 247, an estimated bit-error-rate may be determined. For  
13 example, by comparing the received speech block with the re-coded speech  
14 block, the existence of any error-correction which has taken place within  
15 channel decoder will become apparent. Consequently, this dynamic method  
16 of error detection is considerably more sensitive than other estimates of the  
17 BER, and may be done on a block-by-block basis.

18       An additional metric, SRXQ, is defined as the weighed sum of prior  
19 RXQ' measurements. The SRXQ metric is intended to introduce some  
20 history into the vocoder rate decision making process based on the receiver  
21 quality. In one embodiment, the RXQ' measurements for the prior five (5)  
22 blocks are considered in the SRXQ measurement. The prior RXQ'  
23 measurements are weighted in accordance with the following equation:

1                                 $SRXQ = \text{SUM} (2^{K-1})(RXQ'(K+4));$

2                                where  $K=-4, -3, -2, -1$ , and 0, and where  $RXQ'(0)$  is the  
3       measured value for the most recent block.

4                                An alternative channel quality metric, Frame Erase (FE), may be used  
5       to determine the overall quality of the channel. The FE metric represents the  
6       number of frames which have been determined to be corrupted, and  
7       consequently not used in re-generating the original voice data. In other  
8       words, the FE metric represents a count of the number of frames which have  
9       been erased per unit time. The decision to erase a frame may be made  
10      using a number of criterion. In a present embodiment, the determination to  
11      erase a frame is made based on the cyclic-redundancy-checking (CRC), also  
12      generally known as a "parity" check. Based on a CRC value which is  
13      decoded from the received frame, a frame is either used or discarded,  
14      avoiding the use of a frame which may have been improperly decoded or  
15      otherwise corrupted.

16      System Operation

17                              Referring now to Figure 5, a state diagram is shown and generally  
18      designated 500. State diagram 500 represents the changes in vocoder and  
19      channel coding rates in response to changes in the communication system  
20      environment. For discussion purposes, it is assumed that the communication  
21      system is initially experiencing a high carrier-to-noise ratio (C/N), and thus the  
22      system is initially in state 502 having a relatively high vocoder rate of 8

1 Kbits/s, with a correspondingly low level of channel coding. In other words,  
2 state 502 is used in low-noise environments, such as where the carrier-to-  
3 interference ration (C/I) exceeds 19 dB, wherein the majority of digital  
4 information with a speech block may be voice data. System 100 will remain  
5 in state 502 so long as the FE metric remains at zero (0), as indicated by  
6 control path 508. This results in a communication system having a superior  
7 voice quality.

8 In the event that a frame is erased resulting in the FE metric becoming  
9 non-zero, the BER is computed to determine whether it meets or exceeds a  
10 threshold value. In the present embodiment, this threshold value is one  
11 percent (1%), meaning that if more than one bit out of a total bit stream of  
12 one hundred (100) bits is erroneous, the threshold is met or exceeded. Once  
13 the FE metric becomes non-zero and the BER is above the one percent (1%)  
14 threshold, the system changes to state 504 via control path 510.

15 State 504 is used in environments exhibiting moderate levels of noise  
16 and interference, and combines a mid-range vocoder rate of 6 Kbits/s with a  
17 moderate level of channel coding. In the current example, the vocoder and  
18 channel coding rate will remain at the mid-range of state 504 so long as the  
19 BER is greater-than-or-equal-to one percent (1%), and less than five percent  
20 (5%) ( $1\% \leq \text{BER} < 5\%$ ). In this state, typically where the C/I is between 10  
21 and 19 dB, the communication channel exhibits a reasonably good voice  
22 quality.

1           If after a period of time the communication environment improves and  
2   the FE metric returns to zero (0) and the BER becomes less than one percent  
3   (1%), the system returns to state 502 via control path 512. On the other  
4   hand, in the event the system environment becomes more noisy and the  
5   channel-to-noise ratio (C/N) becomes smaller, the FE metric will likely  
6   increase. If the FE metric increases to equal or exceed 5, and the BER  
7   metric is greater-than-or-equal-to 5 percent (5%), (FE>5 and 5%  $\leq$  BER) the  
8   system passes to state 506 via control path 516. In this state, a higher  
9   degree of channel coding is implemented resulting in a corresponding lower  
10   vocoder rate of 4 Kbits/s. According to control path 520, the system will  
11   remain in state 506 so long as the BER is greater-than-or-equal-to 5% (5%  $\leq$   
12   BER), typically when the C/I is between 4 to 10 dB.

13           When the system is in state 506, and the communication environment  
14   improves causing the FE metric to decrease to zero (0) and the BER metric  
15   to decrease to less than five percent (5%), then the communication system  
16   will change to state 504 according to control path 518, thereby decreasing  
17   the level of channel coding and improving the voice quality of the system.

18           In the event the communication system is in state 506 and the FE and  
19   BER metrics continue to increase, the communication system may eventually  
20   discontinue the communication channel resulting in a "dropped call." In the  
21   present embodiment, the communication channel will be discontinued when  
22   the FE and BER rates exceed 20 and ten percent (10%), respectively, for  
23   example.

1 In order to ensure the proper operation of the system of the present  
2 invention, it is necessary that the metrics evaluated for determination of the  
3 system control between various states 502, 504, and 506 include a measure  
4 of hysteresis. For example, if no hysteresis were to be included between  
5 states 502 and 504, it would be possible for the system to oscillate rapidly  
6 between the two states, resulting in a vocoder rate and level of channel  
7 coding which varies from frame to frame. Although this continual vocoder  
8 change is possible with the system of the present invention, it is unnecessary  
9 and may result in an inefficient use of system resources.

10 The discussion of the various FE and BER values set forth above is  
11 intended as one example of a preferred embodiment having three (3)  
12 different vocoder and channel coding rates. The FE and BER values set  
13 forth are merely exemplary, and any number of alternative FE and BER  
14 values may be chosen and implemented. The threshold values for the FE  
15 and BER values may be treated as system parameters, and may change for  
16 different vocoders. Also, Figure 5 shows a state diagram with three (3)  
17 states, however, any number of states may be created within the present  
18 invention.

#### 19 Mobile Station Control of Downlink Rate

20 Referring now to Figure 6, a flow chart representing the operation of  
21 the communication system of the present invention is shown and generally  
22 designated 600. In general, this configuration includes the MS determining

1 the proper downlink vocoder rate and level of channel coding. Following this  
2 determination, the MS then transmits the necessary rate information to the  
3 BS.

4 Flow chart 600 begins with first step 602 which includes reception of a  
5 radio-frequency frame at the MS. Following receipt of the frame at the MS,  
6 the soft-coded rate bits are extracted from the frame data in step 604. In a  
7 preferred embodiment of the present invention and as discussed above in  
8 conjunction with Figure 4, these soft-coded rate bits may include three (3) bits  
9 of rate information that can identify up to eight (8) different vocoder and  
10 channel coding rates. The frame data is then convolutionally decoded to yield  
11 the original speech block in step 605.

12 Using the appropriate vocoder and channel coding rate information  
13 extracted in step 604, the speech block is then decoded to recreate the  
14 original voice data in step 606. In this manner, the MS may receive a frame  
15 containing voice data encoded with virtually any vocoder rate, and the frame  
16 may be successfully decoded to the original voice data because all relevant  
17 vocoder rate information is transmitted within the frame in the form of soft-  
18 coded bits.

19 In order to provide the best possible voice communication channel, the  
20 MS determines the channel quality metrics discussed above, such as FE,  
21 BER and RXQ, in step 608. The MS also calculates the SRXQ value in step  
22 610 and, based upon the results of the measured and calculated metrics,

1 determines the vocoder rate for optimal voice quality in step 612. In a  
2 preferred embodiment of the present invention, the rate bits corresponding to  
3 the new vocoder and channel coding rate are determined from a look-up  
4 table. Once the vocoder and channel coding rate is determined, the MS  
5 transmits a frame with the new downlink vocoder rate convolutionally coded  
6 into the frame in step 614. Uplink 626 represents the transmission of a frame  
7 from the MS to the BS.

8 In step 616, the BS receives the frame containing the convolutionally-  
9 coded downlink vocoder rate for the next downlink transmission. Because it  
10 is not necessary to know the downlink vocoder rate in order to decode the  
11 uplink transmission, the downlink vocoder rate may be convolutionally  
12 encoded instead of soft-coded.

13 In step 618, the BS decodes the received frame from the MS yielding  
14 the new downlink vocoder rate bits. These vocoder rate bits are used to  
15 determine, using a look-up table or the like, the new downlink vocoder rate.  
16 Using that newly determined vocoder rate, the BS encodes the voice data in  
17 step 619 for transmission to the MS. In step 620, the BS transmits the frame  
18 containing the convolutionally encoded voice data and coded downlink  
19 vocoder rate bits to the MS. Downlink 628 represents the transmission of a  
20 frame from the BS to the MS.

21 Importantly, each downlink message includes as soft-coded bits the  
22 rate information related to the speech block. This is so because there exists

1 a possibility that a frame may become corrupted and no longer readable.  
2 This corruption may create a situation wherein the MS may have transmitted  
3 a message frame in the uplink changing the downlink vocoder rate, and that  
4 frame was not successfully received by the BS. If this occurs, the MS would  
5 expect to receive a frame having a new vocoder rate, while the frame actually  
6 received would be encoded at the old rate. Additionally, in circumstances  
7 involving discontinuous transmissions (DTX), such as when the MS is not  
8 transmitting to save battery power, the channel characteristics and  
9 corresponding vocoder rate information could change significantly between  
10 transmitted frames. Consequently, in order to avoid such mis-communication,  
11 each speech block is soft-coded with the rate information necessary to  
12 decode the speech block.

13 In a preferred embodiment of the present invention as shown in Figure  
14 6, steps within sequence 600 identified by bracket 622 are performed within  
15 the MS, and steps within sequence 600 identified by bracket 624 are  
16 performed within the BS.

17 In any one cycle of uplink-downlink transmissions shown in Figure 6,  
18 both the BS and the MS will inform the other of the appropriate vocoder rates  
19 for the transmitted message. For example, in an uplink frame containing  
20 convolutionally-coded rate bits for the next downlink frame, soft-coded rate  
21 bits will be present which will tell the BS what vocoder rate to use in decoding  
22 the uplink frame. Similarly, in a downlink frame containing convolutionally-  
23 coded rate bits for the next uplink frame, soft-coded rate bits will be present



1 which will tell the MS what vocoder rate to use in decoding that downlink  
2 frame.

3 In the communication system of the present invention, it has been  
4 termed that vocoder rate bits which are not convolutionally encoded are "soft-  
5 coded" into the speech block, and the vocoder rate bits which are  
6 convolutionally encoded are "hard-coded" into the speech block. As an  
7 alternative terminology, the vocoder rate information which is convolutionally  
8 encoded into a speech block could also be considered an "inside" rate, as the  
9 vocoder rate information is within the convolutional coding. Vocoder rate  
10 information which is soft-coded into the speech-block is considered an  
11 "outside" rate, as the vocoder rate information is outside the convolutional  
12 coding.

### 13 Base Station Control of Downlink

14 Referring now to Figure 7, a flow chart representing the operation of  
15 an alternative embodiment of the communication system of the present  
16 invention is shown and generally designated 700. In general, this  
17 configuration includes the MS monitoring a series of channel metrics and  
18 relaying this metric information to the BS for determining the proper downlink  
19 vocoder rate and level of channel coding. Following this determination, the  
20 BS then transmits the soft-coded rate bits to the MS with the following frame.

21 In first step 702, the MS receives a frame with soft-coded rate bits. In  
22 step 703, the MS extracts the soft-coded rate bits from the frame, and using a

1 look-up table or the like, determines the appropriate downlink vocoder rate  
2 and level of channel coding. In step 704, using this rate information, the MS  
3 decodes the frame, yielding a speech block. In step 706, the vocoders are  
4 set to the appropriate rate and this speech block is decoded to re-create the  
5 original voice in the speech block.

6 During the decoding process, the MS is determining the channel  
7 quality of the communication system. For example, quality metrics such as  
8 FE and RXQ may be determined in step 708. Following the determination of  
9 FE and RXQ, a quantized vocoder value is determined in step 710 which  
10 reflects the current communication channel quality. Referring ahead briefly to  
11 Figure 8, a quantization table is shown and generally designated 800.  
12 Quantization table 800 includes both the FE metric 802 and the RXQ metric  
13 804 which are measured at the MS, and lists a number of non-uniform  
14 quantization values for each. These RXQ' values are the mid-range of the  
15 transmitted quantization levels, and represent a range of RXQ' metric values.  
16 Since the FE and RXQ' are both associated with the receiver performance,  
17 the quantization of RXQ' is based on the value of FE to effectively quantize  
18 RXQ' into eight levels. By locating the current measured values of both the  
19 FE and RXQ on the quantization table, a series of three (3) quantization bits  
20 are identified. For instance, for a FE value of 1 and a RXQ value of 25,  
21 quantization bits 1-0-0 are selected. Once the quantization bits are selected,  
22 in step 712 a frame is transmitted from the MS to the BS with the quantization

1 bits fully encoded in the speech block. Uplink 730 represents the  
2 transmission of a frame from the MS to the BS.

3 In step 714, the frame is received at the BS with the quantization bits  
4 fully encoded. This frame is decoded in step 716 to yield the original  
5 quantization bits. Referring briefly to Figure 9, a quantization table 900 is  
6 shown which provides a look-up table to reconstruct the FE and RXQ' values  
7 from the received quantization bits. For example, for quantization bits 1-0-0,  
8 a FE metric value 904 of "1" and an RXQ metric value 906 of "22." These  
9 metrics derived from the quantization bits are then used to calculate the  
10 SRXQ metric in step 718. Based upon the quantization bits and the results of  
11 the SRXQ calculation, a new vocoder rate is determined in step 720 by the  
12 MS. In step 722, voice data for the next speech block is encoded using the  
13 new vocoder rate, with the new vocoder rate bits being soft-coded into the  
14 speech block resulting in a new frame. This new frame is then transmitted  
15 from the BS to the MS in step 724. Downlink 732 represents the  
16 transmission of a frame from the BS to the MS.

#### 17 Base Station Control of Uplink

18 In addition to the rate bits which are exchanged between the MS and  
19 the BS to govern the downlink vocoder and channel coding rate, the rate bits  
20 corresponding to the operation of the uplink are also exchanged. This is  
21 accomplished by the BS analyzing similar channel quality metrics which are

1 used to determine the appropriate downlink vocoder rate as discussed in  
2 conjunction with Figure 6.

3 Referring now to Figure 10, a flow chart representing the operation of  
4 an alternative embodiment of the communication system of the present  
5 invention is shown and generally designated 1000. In general, this  
6 configuration includes the BS monitoring a series of channel metrics  
7 determines the proper uplink vocoder rate and level of channel coding.  
8 Following this determination, the MS then transmits the soft-coded rate bits to  
9 the BS with the following frame.

10 Flow chart 1000 begins with first step 1002 which includes reception of  
11 a radio-frequency frame at the BS. Following receipt of the frame at the BS,  
12 the soft-coded rate bits are extracted from the frame data in step 1004. In a  
13 preferred embodiment of the present invention and as discussed above in  
14 conjunction with Figure 4, these soft-coded rate bits may include three (3) bits  
15 of rate information that can identify up to eight (8) different vocoder and  
16 channel coding rates. The frame data is then convolutionally decoded to yield  
17 the original speech block in step 1006.

18 Using the appropriate vocoder and channel coding rate information  
19 extracted in step 1004, the speech block is then decoded to recreate the  
20 original voice data in step 1008. In this manner, the BS may receive a frame  
21 containing voice data encoded with virtually any vocoder rate, and the frame  
22 may be successfully decoded to the original voice data because all relevant

1   vocoder rate information is transmitted within the frame in the form of soft-  
2   coded bits.

3           In order to provide the best possible voice communication channel, the  
4   BS determines the channel quality metrics discussed above, such as FE,  
5   BER and RXQ, in step 1010. The BS also calculates the SRXQ value in step  
6   1012 and, based upon the results of the measured and calculated metrics,  
7   determines the vocoder rate for optimal voice quality in step 1014. In a  
8   preferred embodiment of the present invention, the rate bits corresponding to  
9   the new vocoder and channel coding rate are determined from a look-up  
10  table. Once the vocoder and channel coding rate is determined, the BS  
11  transmits a frame with the new uplink vocoder rate convolutionally coded into  
12  the frame in step 1016. Downlink 1018 represents the transmission of a  
13  frame from the BS to the MS.

14           In step 1020, the MS receives the frame containing the  
15  convolutionally-coded uplink vocoder rate for the next downlink transmission.  
16  Because it is not necessary to know the uplink vocoder rate in order to  
17  decode the uplink transmission, the uplink vocoder rate may be  
18  convolutionally encoded instead of soft-coded.

19           In step 1022, the MS decodes the received frame from the BS yielding  
20  the new uplink vocoder rate bits. These vocoder rate bits are used to  
21  determine, using a look-up table or the like, the new uplink vocoder rate.  
22  Using that newly determined vocoder rate, the MS encodes the voice data in

1 step 1024 for transmission to the BS. In step 1026, the MS transmits the  
2 frame containing the convolutionally encoded voice data and soft-coded  
3 uplink vocoder rate bits to the BS. Uplink 1028 represents the transmission  
4 of a frame from the MS to the BS.

5       Importantly, each uplink message includes as soft-coded bits the rate  
6 information related to the speech block. This soft-coding enables the BS to  
7 properly decode the speech block without knowing in advance the vocoder  
8 rate. This is particularly advantageous because there exists a possibility that  
9 a frame may become corrupted and no longer readable. This corruption may  
10 create a situation wherein the BS may have transmitted a message frame in  
11 the downlink changing the uplink vocoder rate, and that frame was not  
12 successfully received by the MS. If this occurs, the BS would expect to  
13 receive a frame having a new vocoder rate, while the frame actually received  
14 would be encoded at the old rate. Additionally, in circumstances involving  
15 discontinuous transmissions (DTX), such as when the BS is not continuously  
16 transmitting, the channel characteristics and corresponding vocoder rate  
17 information could change significantly between transmitted frames.  
18 Consequently, in order to avoid such mis-communication, each speech block  
19 is soft-coded with the rate information necessary to decode the speech block.

20       In a preferred embodiment of the present invention as shown in Figure  
21 10, steps within sequence 1000 identified by bracket 1030 are performed  
22 within the BS, and steps within sequence 1000 identified by bracket 1032 are  
23 performed within the MS.

1

2 System Performance

3       The communication system of the present invention provides for the  
4 block and bit interleaving thereby minimizing the disruption to the  
5 communication link caused by channel noise, interference, and dropped  
6 frames. In addition to such redundancy, the vocoder rate information which is  
7 either hard-coded within the frame or soft-coded outside the frame, may also  
8 be repetitive. Such repetition will further enhance the resilience of the  
9 communication system of the present invention. Redundancy of the vocoder  
10 rate information, or rate bits, may be accomplished by repeating the bits in  
11 several locations within the speech frame, as mentioned above in conjunction  
12 with Figure 4.

13       Like traditional GSM-based communication systems, the  
14 communication system of the present invention provides for the transfer, or  
15 "hand-off," of a MS from one BS to another BS in a different cell. In such a  
16 hand-off, it would not be necessary to provide the new BS with any special  
17 rate information via the communication link 108 as all necessary vocoder rate  
18 information is presented in each frame transmitted from the MS.

19       The present invention may be implemented in either a full-rate or half-  
20 rate GSM-based communication system. The encoding and transmission of  
21 the vocoder rate information between the BS and MS in both the full and half-  
22 rate system would be identical.

1           In addition to the modification of the vocoder rate and channel coding  
2   as discussed above, the power level of the transmissions may also be  
3   modified in order to provide the best possible voice quality. For example, in  
4   Figures 8 and 9, rate bits 806 and 902 may take into consideration, in  
5   addition to the FE and RXQ' metrics, a metric related to the power level of the  
6   transmission. In such a situation, the BS may adjust the vocoder rate and  
7   channel coding, while at the same time adjusting the BS transmit power to  
8   minimize the BER or FE, resulting in better voice quality.

9           While the present invention has been discussed at length with respect  
10   to the transmission of voice data between a BS and a MS, it should be  
11   appreciated that any digital data may be communicated in a similar manner.  
12   In fact, because other types of digital data may not be dependent upon the  
13   audio sampling rates, a much higher data rate may be achieved using the  
14   present invention. and is fully contemplated herein.

#### 15                           OTHER EMBODIMENTS

16           While there have been shown what are presently considered to be  
17   preferred embodiments of the invention, it will be apparent to those skilled in  
18   the art that various changes and modifications can be made herein without  
19   departing from the scope and spirit of the invention as defined by the  
20   appended claims and their equivalents.



**CLAIMS**

What is claimed is:

- 1           1. A wireless communication system comprising:  
2           a mobile station; and  
3           a base station which transmits a downlink signal to the mobile station  
4           wherein the downlink signal includes a downlink rate and  
5           wherein the mobile station extracts the downlink rate from the  
6           downlink signal and decodes the downlink signal using this  
7           extracted downlink rate.
- 1           2. The wireless communication system of claim 1, wherein the  
2           downlink rate is determined by the mobile station using one or more channel  
3           quality metrics.
- 1           3. The wireless communication system of claim 2, wherein the  
2           downlink rate is communicated to the base station by the mobile station  
3           using one or more rate bits in a uplink signal.
- 1           4. The wireless communication system of claim 3, wherein the one or  
2           more rate bits are soft-coded into the uplink signal.
- 1           5. The wireless communication system of claim 2, wherein  
2           determination of the downlink rate comprises comparing one of the one or  
3           more channel quality metrics to a predefined value, and selecting a downlink

4 rate corresponding to the predefined value.

1 6. The wireless communication system of claim 5, wherein the  
2 downlink rate is communicated from the base station to the mobile station  
3 using one or more rate bits in the downlink signal.

1 7. The wireless communication system of claim 6, wherein the one or  
2 more rate bits are soft-coded into the downlink signal.

1 8. The wireless communication system of claim 2, wherein the one or  
2 more channel quality metrics includes a frame erase metric.

1 9. The wireless communication system of claim 2, wherein the one or  
2 more channel quality metrics includes a receive quality metric.

1 10. The wireless communication system of claim 2, wherein the one or  
2 more channel quality metrics includes a bit-error-rate metric.

1 11. The wireless communication system of claim 2, wherein the one or  
2 more channel quality metrics includes an average receive quality metric.

1 12. A wireless communication system comprising:  
2 a mobile station which monitors one or more downlink channel quality  
3 metrics, wherein the mobile station determines one or more  
4 quantization bits corresponding to the one or more downlink  
5 channel quality metrics; and

6 a base station which receives an uplink signal including the one or  
7 more quantization bits from the mobile station, and wherein the  
8 base station determines a downlink rate corresponding to the  
9 one or more  
10 quantization bits and transmits a downlink signal to the mobile  
11 station using the downlink rate.

1 13. The wireless communication system of claim 12, wherein the  
2 downlink signal includes the downlink rate.

1 14. The wireless communication system of claim 12, wherein  
2 determination of the downlink rate comprises comparing one of the one or  
3 more channel quality metrics to a predefined value, and selecting a downlink  
4 rate corresponding to the predefined value.

1 15. The wireless communication system of claim 12, wherein the  
2 downlink rate is communicated from the base station to the mobile station  
3 using one or more rate bits in the downlink signal.

1 16. The wireless communication system of claim 15, wherein the one  
2 or more rate bits are soft-coded into the downlink signal.

1 17. The wireless communication system of claim 12, wherein the one  
2 or more channel quality metrics includes a frame erase metric.

1           18. The wireless communication system of claim 12, wherein the one  
2   or more channel quality metrics includes a receive quality metric.

1           19. The wireless communication system of claim 12, wherein the one  
2   or more channel quality metrics includes a bit-error-rate metric.

1           20. The wireless communication system of claim 12, wherein the one  
2   or more channel quality metrics includes an average receive quality metric.

1           21. A wireless communication system comprising:  
2   a base station; and  
3   a mobile station which transmits an uplink signal to the base station,  
4           wherein the uplink signal includes an uplink rate and wherein  
5           the base station  
6           extracts the uplink rate from the uplink signal and decodes the  
7           uplink signal using this extracted uplink rate.

1           22. The wireless communication system of claim 21, wherein the  
2   uplink rate is determined in the base station and communicated to the mobile  
3   station.

1           23. The wireless communication system of claim 21, wherein the  
2   uplink rate information is determined by the base station using one or more  
3   channel quality metrics.

1           24. The wireless communication system of claim 23, wherein the  
2   channel quality metrics includes a frame erase metric.

1           25. The wireless communication system of claim 23, wherein the  
2   channel quality metrics includes a receive quality metric.

1           26. The wireless communication system of claim 23, wherein the  
2   channel quality metrics includes a bit-error-rate metric.

1           27. The wireless communication system of claim 23, wherein the  
2   channel quality metrics includes an average receive quality metric.

1           28. A method of maximizing voice quality in a wireless communication  
2   system including a base station and a mobile station, the method comprising  
3   the steps of:  
4       determining the quality of a downlink communication channel in the  
5           mobile station using one or more channel quality metrics;  
6       determining a new downlink rate based on the channel quality metrics;  
7       transmitting the new downlink rate from the mobile station to the base  
8           station  
9           in an uplink signal;  
10      extracting the new downlink rate from the uplink signal;  
11      creating a downlink signal using the new downlink rate;  
12      encoding the new downlink rate into the downlink signal;

13 transmitting the downlink signal from the base station to the mobile  
14 station;  
15 receiving the downlink signal at the mobile station;  
16 extracting the new downlink rate from the downlink signal; and  
17 decoding the downlink signal using the extracted new downlink rate.

1 29. A method of maximizing voice quality in a wireless communication  
2 system including a base station and a mobile station, the method comprising  
3 the steps of:  
4 determining the quality of a downlink communication channel in the  
5 mobile station using one or more channel quality metrics;  
6 selecting one or more quantization bits corresponding to the one or  
7 more  
8 channel quality metrics from a predetermined group of  
9 quantization bits;  
10 transmitting the quantization bits from the mobile station to the base  
11 station in an uplink signal;  
12 extracting the quantization bits from the uplink signal in the base  
13 station;  
14 determining a downlink rate from the extracted quantization bits;  
15 creating a downlink signal using the downlink rate;  
16 encoding the downlink rate into the downlink signal;  
17 transmitting the downlink signal from the base station to the mobile

18 station;  
19 receiving the downlink signal at the mobile station;  
20 extracting the downlink rate from the downlink signal; and  
21 decoding the downlink signal using the extracted downlink rate.

1 30. A method of maximizing voice quality in a wireless communication  
2 system including a base station and a mobile station, the method comprising  
3 the steps of:  
4 determining the quality of an uplink communication channel in the  
5 base  
6 station using one or more channel quality metrics;  
7 determining an uplink rate based on the channel quality metrics;  
8 transmitting the uplink rate from the base station to the mobile station  
9 in a downlink signal;  
10 extracting the uplink rate from the downlink signal;  
11 creating an uplink signal using the uplink rate;  
12 encoding the new uplink rate into the uplink signal;  
13 transmitting the uplink signal from the mobile station to the base  
14 station;  
15 receiving the uplink signal at the base station;  
16 extracting the new uplink rate from the uplink signal; and  
17 decoding the uplink signal using the extracted uplink rate.

- 1           31. A wireless communication system comprising:  
2           means for determining the quality of a downlink communication  
3                 channel in the mobile station using one or more channel quality  
4                 metrics;  
5           means for determining a new downlink rate based on the channel  
6                 quality metrics;  
7           means for transmitting the new downlink rate from the mobile station to  
8                 the  
9                 base station in an uplink signal;  
10          means for extracting the new downlink rate from the uplink signal;  
11          means for creating a downlink signal using the new downlink rate;  
12          means for encoding the new downlink rate into the downlink signal;  
13          means for transmitting the downlink signal from the base station to the  
14                 mobile station;  
15          means for receiving the downlink signal at the mobile station;  
16          means for extracting the new downlink rate from the downlink signal;  
17                 and  
18          means for decoding the downlink signal using the extracted new  
19                 downlink rate.

- 1           32. A wireless communication system comprising:  
2           means for determining the quality of a downlink communication  
3                 channel in



4 the mobile station using one or more channel quality metrics;  
5 means for selecting one or more quantization bits corresponding to the  
6 one or more channel quality metrics from a predetermined  
7 group of  
8 quantization bits;  
9 means for transmitting the quantization bits from the mobile station to  
10 the  
11 base station in an uplink signal;  
12 means for extracting the quantization bits from the uplink signal in the  
13 base station;  
14 means for determining a downlink rate from the extracted quantization  
15 bits;  
16 means for creating a downlink signal using the downlink rate;  
17 means for encoding the downlink rate into the downlink signal;  
18 means for transmitting the downlink signal from the base station to the  
19 mobile station;  
20 means for receiving the downlink signal at the mobile station;  
21 means for extracting the downlink rate from the downlink signal; and  
22 means for decoding the downlink signal using the extracted downlink  
23 rate.

1 33. A wireless communication system comprising:  
2 means for determining the quality of an uplink communication channel

3                   in the base station using one or more channel quality metrics;  
4           means for determining an uplink rate based on the channel quality  
5                   metrics;  
6           means for transmitting the uplink rate from the base station to the  
7                   mobile station in a downlink signal;  
8           means for extracting the uplink rate from the downlink signal;  
9           means for creating an uplink signal using the uplink rate;  
10          means for encoding the new uplink rate into the uplink signal;  
11          means for transmitting the uplink signal from the mobile station to the  
12                   base station;  
13          means for receiving the uplink signal at the base station;  
14          means for extracting the new uplink rate from the uplink signal; and  
15          means for decoding the uplink signal using the extracted uplink rate.

1          34. A wireless communication system, comprising:  
2           a base station;  
3           a mobile station which receives a downlink signal from the base station  
4                   over a downlink, the downlink signal having a ratio of voice data  
5                   to channel coding;  
6           means for determining the quality of the downlink; and  
7           means for adjusting the ratio of the voice data to channel coding of the  
8                   downlink signal to improve the quality of the downlink.

1           35. The wireless communication system of claim 34, wherein the  
2 means for determining the quality of the downlink comprises one or more  
3 channel quality metrics.

1           36. A wireless communication system, comprising:  
2 a mobile station;  
3 a base station which receives an uplink signal from the mobile station  
4 over an uplink, the uplink signal having a ratio of voice data to  
5 channel coding;  
6 means for determining the quality of the uplink; and  
7 means for adjusting the ratio of the voice data to channel coding of the  
8 uplink signal to improve the quality of the uplink.

1           37. The wireless communication system of claim 36, wherein the  
2 means for determining the quality of the uplink comprises one or more  
3 channel quality metrics.

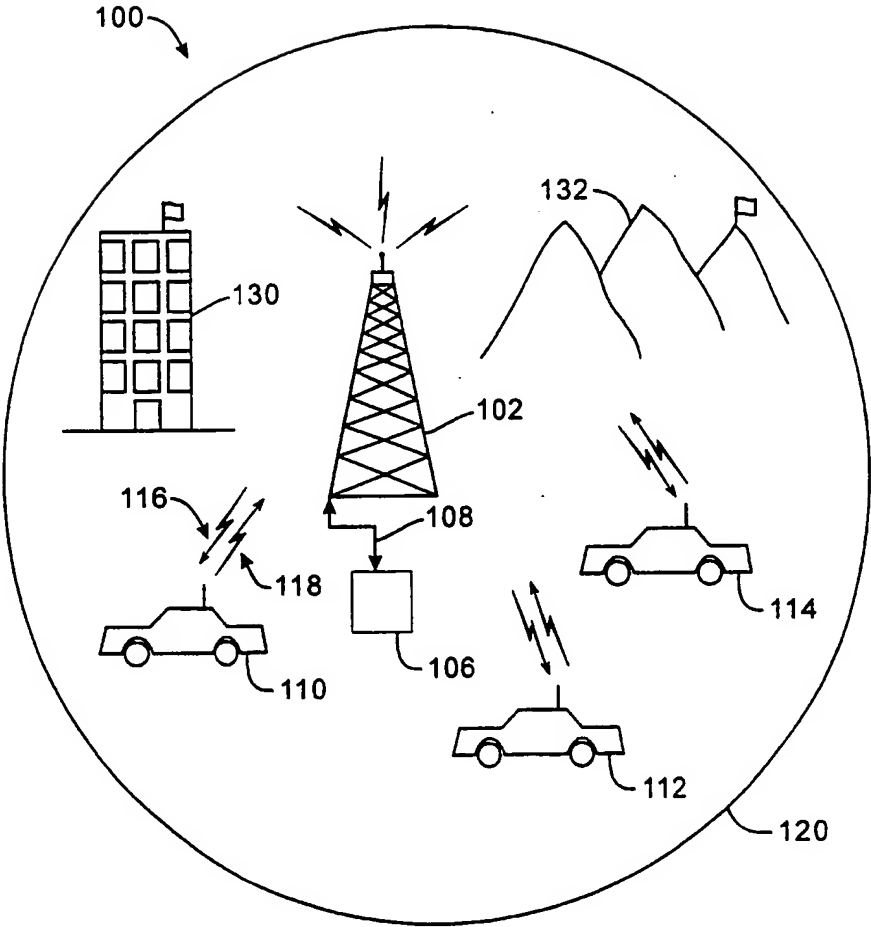


Fig. 1

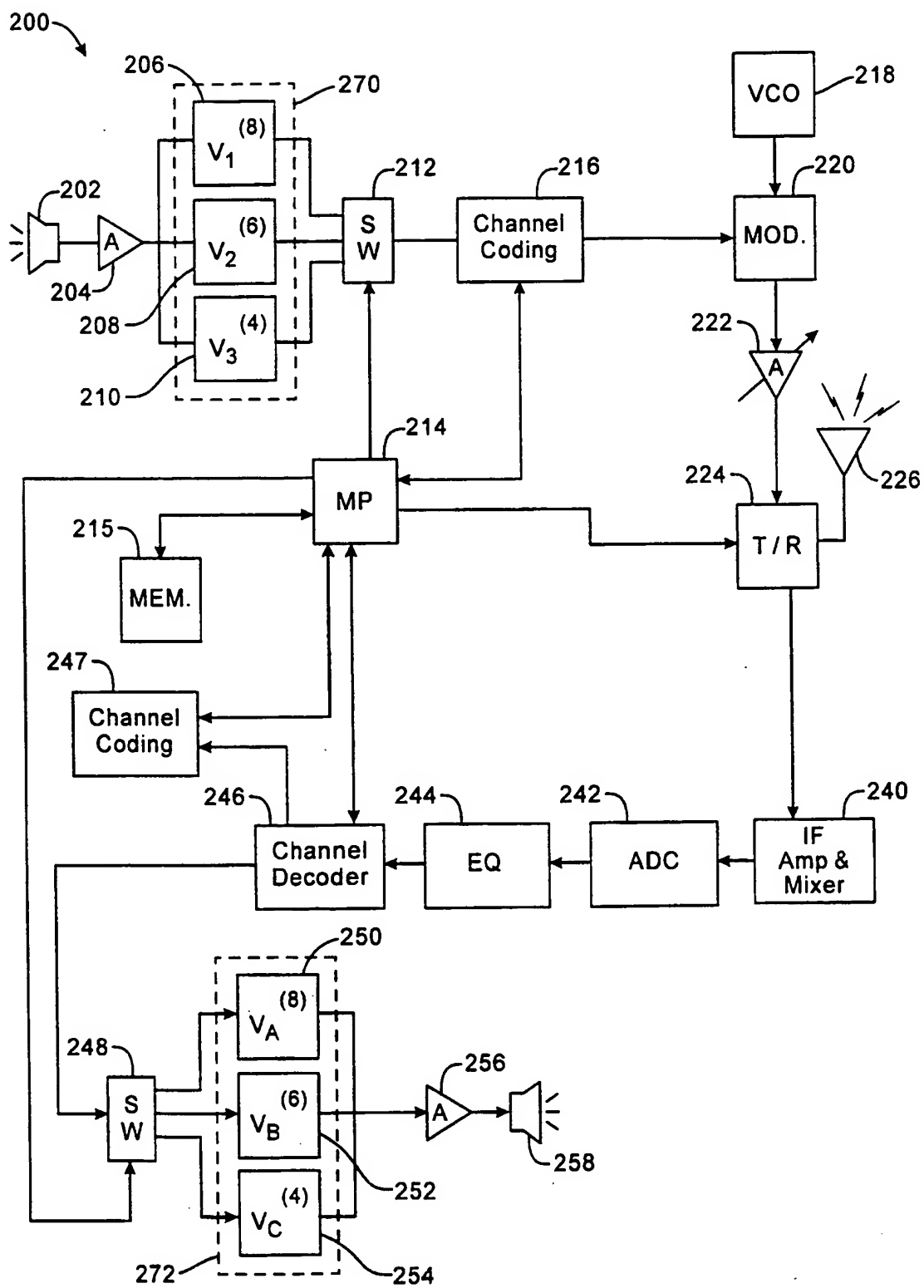


Fig. 2

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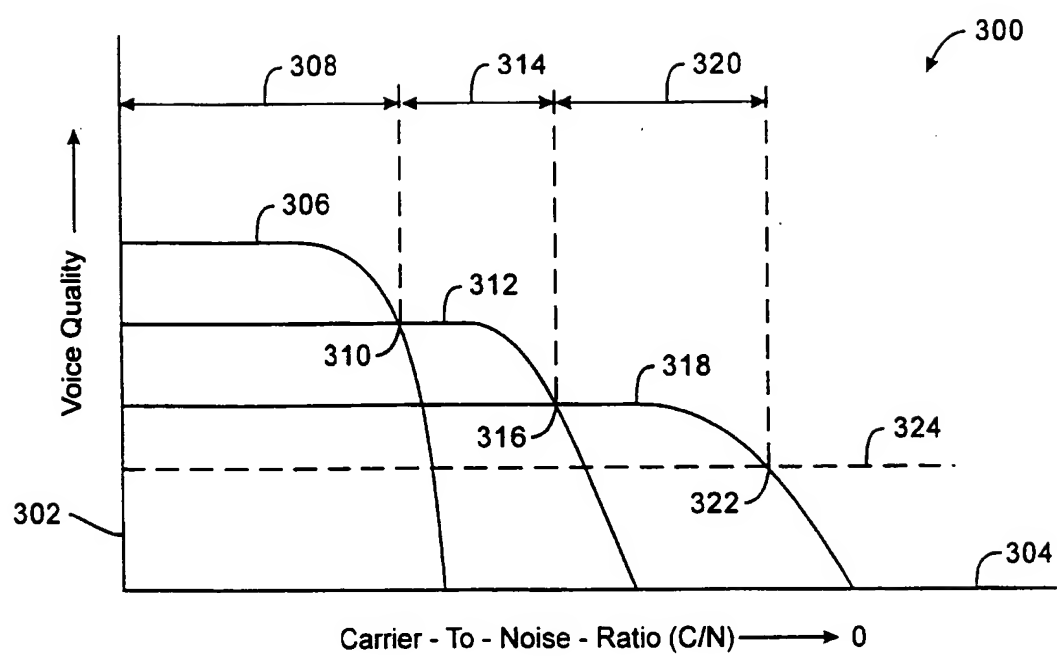


Fig.3

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400

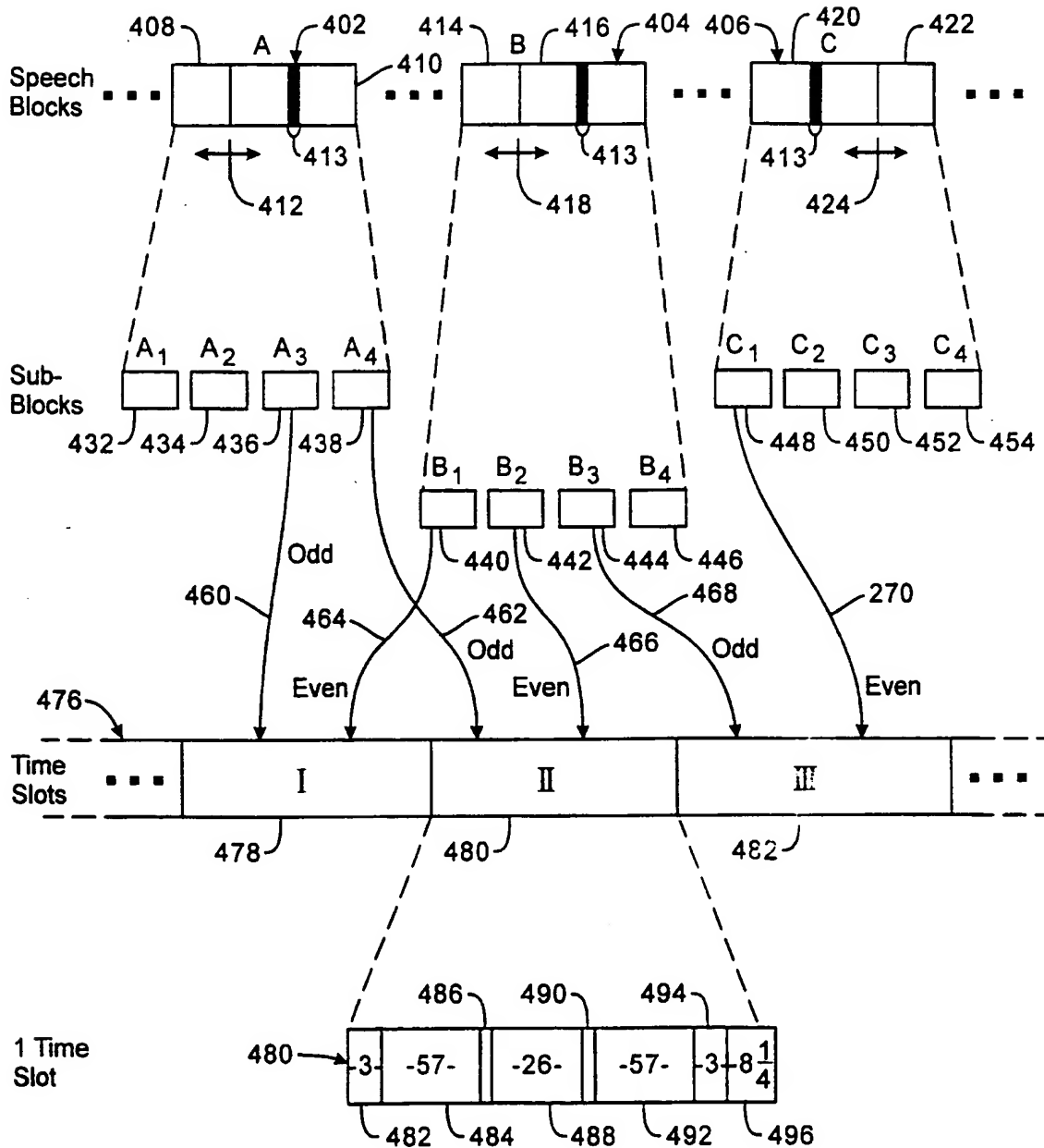


Fig. 4

SUBSTITUTE SHEET (RULE 26)

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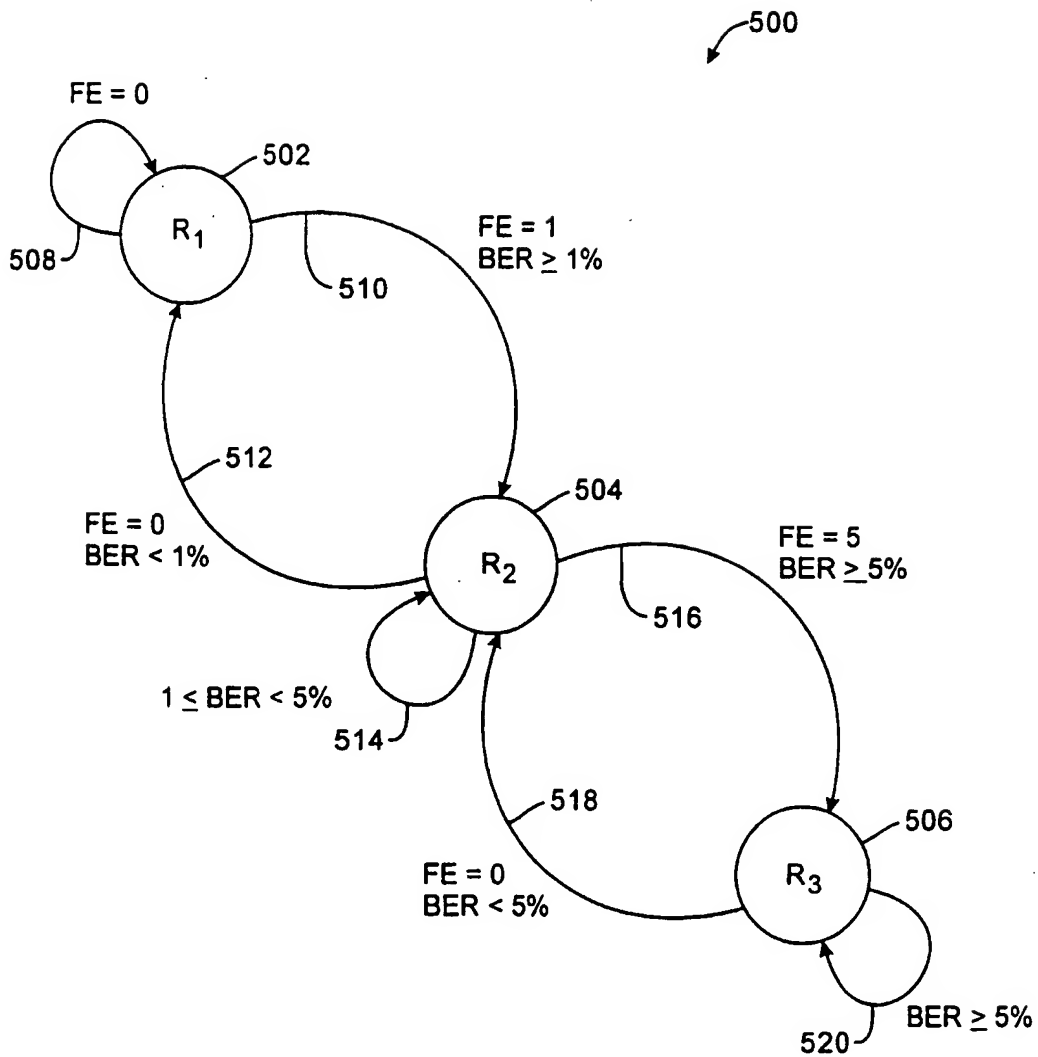


Fig. 5

SUBSTITUTE SHEET (RULE 26)



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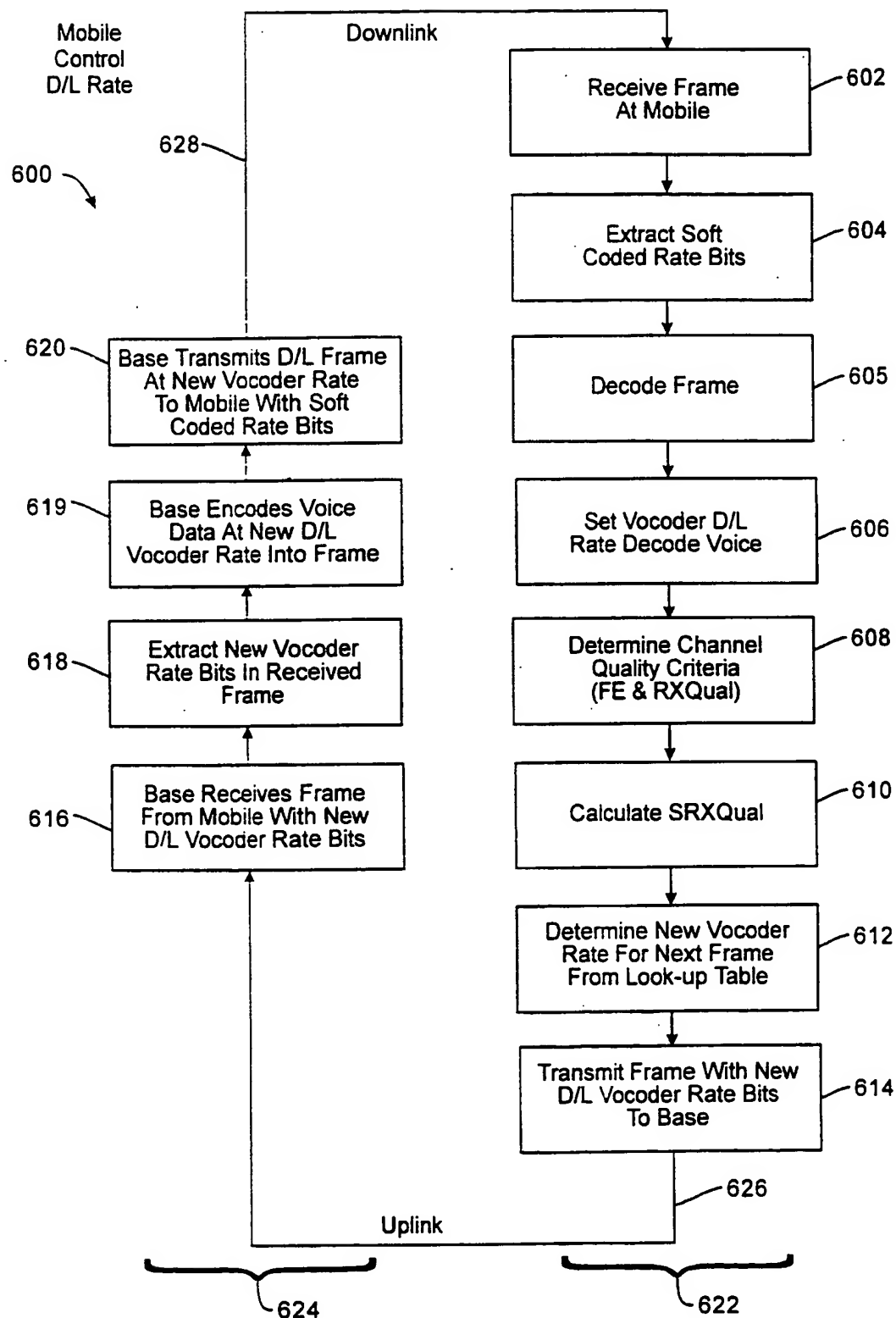


Fig. 6

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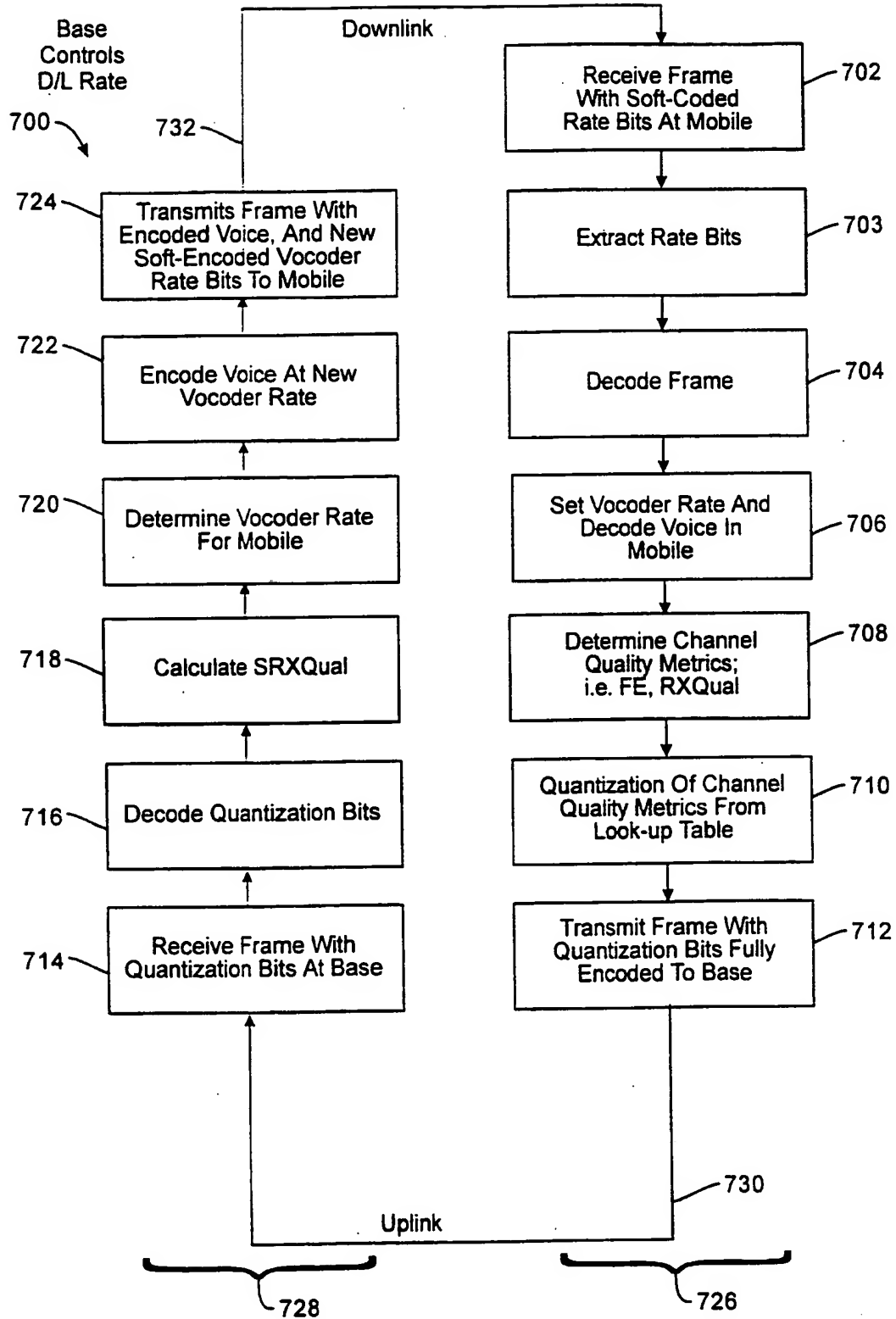


Fig. 7

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(Quantization Table For The Mobile)

802	Frame Erase (FE)	RXQual < = 804	Transmitted Bits	806
	0	5	000	800
	0	10	001	
	0	15	010	
	0	20	011	
	1	25	100	
	1	35	101	
	1	60	110	
	1	80	111	

Fig. 8

(Quantization Table For The Base Station)

902	Received Bits	Frame Eraser (FE) 904	RXQual	906
900	000	0	2	
	001	0	7	
	010	0	12	
	011	0	17	
	100	1	22	
	101	1	29	
	110	1	37	
	111	1	65	

Fig. 9

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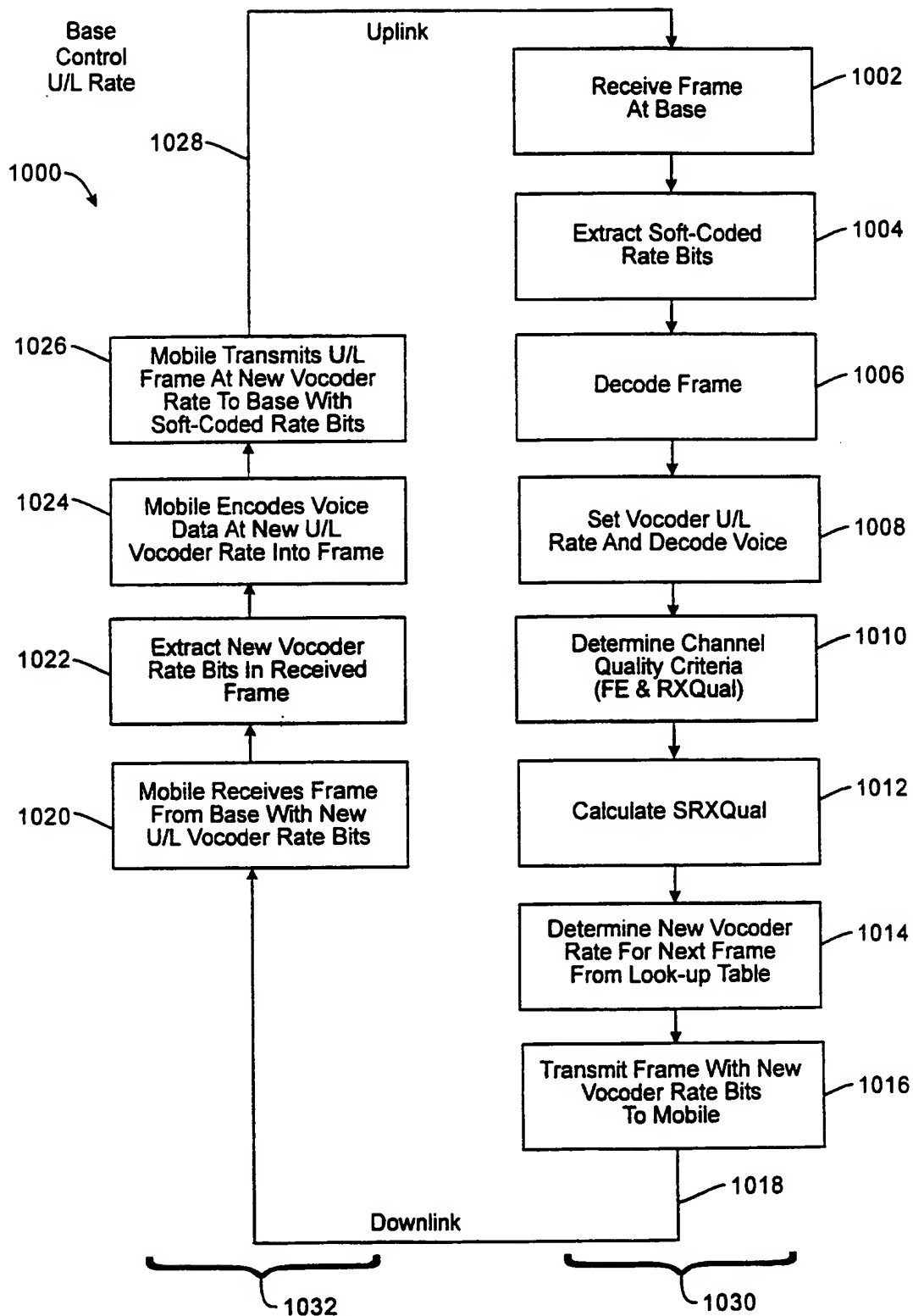


Fig. 10

# INTERNATIONAL SEARCH REPORT

International Application No

PC:US 99/10775

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 H04L1/12

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 03030 A (NOKIA MOBILE PHONES LTD ;JOKINEN HARRI (FI); HAKASTE MARKUS (FI);) 22 January 1998 (1998-01-22)  abstract page 3, line 4 - line 12 page 3, line 21 - line 25 page 5, line 4 - line 16 page 5, line 36 - line 37 page 6, line 21 - line 26 page 7, line 31 - page 8, line 4 figures 1-4	1-3, 5, 6, 9, 10, 12-15, 18, 19, 21-23, 25, 26, 28, 30, 31, 33-37
Y		8, 11, 17, 20, 24, 27, 29, 32
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/10775

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Y	<p>WO 96 22639 A (QUALCOMM INC) 25 July 1996 (1996-07-25) page 20, line 37 - page 21, line 8</p>	<p>8, 17, 24</p>
Y	<p>GB 2 306 867 A (BOSCH GMBH ROBERT) 7 May 1997 (1997-05-07) abstract page 2, line 2 - line 9 page 2, line 26 - line 30 page 3, line 12 - line 21 page 4, line 1 - line 18 figure 2</p>	<p>11, 20, 27, 29, 32</p>

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